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State of Modeling Symmetry in Hohlraums

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State of Modeling Symmetry in Hohlraums*

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Summary:
- Modeling radiation drive asymmetry is challenging problem whose agreement with data depends on the hohlraum gas fill density.
- Modeling to date uses the HYDRA code with crossbeam energy transfer (CBET) calculated separately, and backscattered light removed from the input laser.
- For high fill hohlraums (~>1 mg/cc), matching symmetry requires ad hoc adjustments to CBET during picket and peak of drive.
- For near-vacuum hohlraums, there is little CBET or backscatter, and drive is more waist-high than predicted.
- For intermediate fill densities (~0.6 mg/cc) there appears to be a region of small CBET and backscatter where symmetry is reasonably well modeled.
- A new technique where backscatter and CBET are done "inline" appears it could bring high fill simulations closer to data.

Modeling radiation drive asymmetry is a challenging problem

Low mode asymmetry (Legendre mode ≤8) in an indirect drive implosion originates from three sources: hohlraum radiation drive asymmetry, capsule support tent, or out of round capsule or ice layer. This paper will focus on radiation drive asymmetry.

A number of physical processes are important in determining the radiation asymmetry. These include inverse Bremsstrahlung absorption of the laser light, refraction, hohlraum wall motion, hohlraum wall albedo, cross beam energy transfer (CBET), and laser backscatter. Asymmetry is amplified by the convergence of the capsule so asymmetries in drive of ~1% are important – this is why modeling asymmetry is a challenging and experiments are needed to benchmark the simulations.

Our hohlraum experiments currently fall into three types, depending on the processes that control implosion symmetry:
- High gas-fill hohlraum (~>1 mg/cc He fill) symmetry is dominated by backscatter and cross beam energy transfer.
- Near-vacuum hohlraum (~0.06 mg/cc He fill) symmetry is dominated by unimpeded hohlraum wall motion and colliding plasmas as the wall crashes into the ablated capsule material.
- Intermediate gas-fill hohlraum (~0.3-0.6 mg/cc fill) may be a "sweet spot" in hohlraum design space with low LPI and without colliding plasmas.

The focus of our program over the next several years will be on near-vacuum and intermediate gas-fill hohlraums.

Description of standard multi-step calculation procedure

In current routine radiation-hydrodynamic (RH) modeling in both HYDRA and LASNEX, CBET is calculated using coupled-mode equations in the strong damping limit [1]. Backscatter is not calculated, but instead is given as an input. Post-shot simulations are done in a three-step process using the so-called "high flux model" (HFM) [2]. Step one is an RH

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simulation with the full, incident laser power, with no CBET or backscatter. The purpose is to maintain a more accurate estimate of the laser intensity in the LEH where the beams cross and undergo CBET. Step two consists of calculating the CBET separately using the calculated plasma conditions. Step three consists of re-running the RH simulation using the calculated CBET and with the backscatter removed at the lens (before it enters the grid). This is clearly an idealization since the backscattered light grows from thermal noise within the hohlraum and is partly re-absorbed as it propagates out, resulting in higher laser intensity in the laser entrance hole (LEH) than when it is simply removed. The three-step process also neglects any LPI-driven plasma waves, namely ion-acoustic waves and their deposited energy from CBET [ref Michel PRL 2012], and Langmuir waves and the resulting hot electrons from SRS.

High gas fill hohlraums

Gas fill is used to tamp the motion of the hohlraum wall and allow longer laser pulses. However, these hohlraums also have large amounts of backscatter and cross beam transfer. The experimental drive symmetry is inferred from imaging a high-Z "re-emit" capsule, multi-axis shock timing data, backlit radiographs of the inflight shell, and self-emission images of the hotspot near peak x-ray emission. Simulations are post-processed using appropriate filtering in order to generate simulated data to compare against the experiment. For CH implosions with ρ_{fill} = 1-1.6 mg/cc) we need more transfer than calculated to match P2/P0 symmetry during the first picket (0-2 ns), and less than calculated to match P2/P0 during peak drive. Improved agreement between the model and measurements for a series of CH implosions is achieved by artificially saturating the transfer via a non-physical clamp on ion wave amplitude $\delta n_e/n_e$, as shown in Fig. 1. Here the saturation value was tuned to approximately match each shot, so this prescription is not predictive. When we forced a match of the inflight P2/P0 symmetry, the P4/P0 was also correct (Fig. 2), suggesting the code is placing the radiation spots in approximately the correct location (P4/P0 depends mostly on relative position of laser spot emission). However, the tent scar, visible in some experimental backlit images and not included in these simulations, grows enough by stagnation to significantly alter the hotspot shape, especially P4/P0.

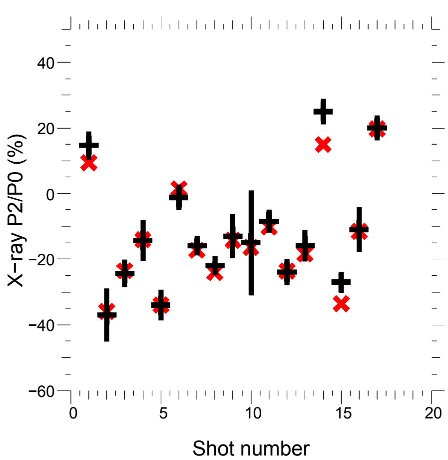

Fig 1: Simulated (red) and experimental (black) hot spot P2/P0 distortion for series of high foot CH implosions.

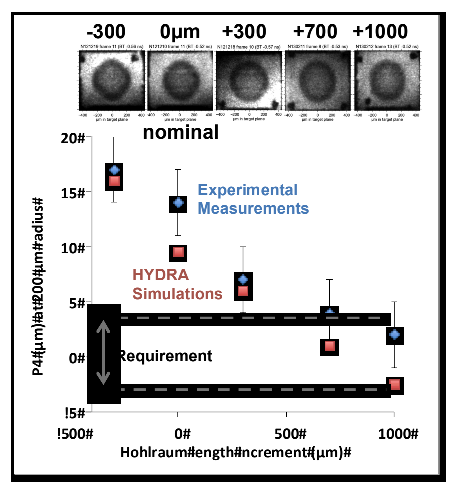

Fig 2: Scaling of inflight P4/P0 distortion with hohlraum length.

Near-vacuum hohlraums

The HDC near-vacuum hohlraum experiments (ρ_{fill} = 0.03-0.06 mg/cc) are in a significantly different modeling regime. For example, these experiments have minimal backscatter (<3% of incident laser energy) and little CBET ($\delta\lambda$ = 0 Å). HYDRA HFM calculations predict a large increase in electron density when plasma blow-off from the ablator and the Au wall meet. The inner cone laser power is absorbed in this region near the outer cone due to the large increase in plasma density. This leads to a pole high flux and oblate implosions, whereas in the experiment we infer that the inner cone propagates to the waist, causing a waist high flux and leading to observed prolate implosions. The initial spike in simulated electron density may not accurately describe the time-dependence of the two counter-streaming plasmas. A leading hypothesis is that the code is incorrectly calculating the stagnation of the wall and ablator plasmas, and that those plasmas are actually interpenetrating, leading to lower stagnation densities. One way to allow the laser beams to propagate through the spike in density for a longer distance and give a better match to the measured symmetry is to change their frequency, as shown in Fig. 3.

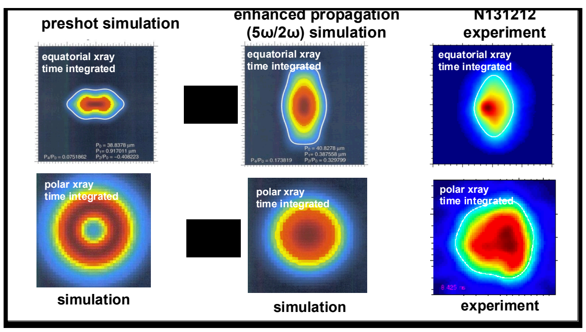

Fig 3: Hydra HFM calculation requires enhanced inner cone propagation to match near-vacuum experimental shape.

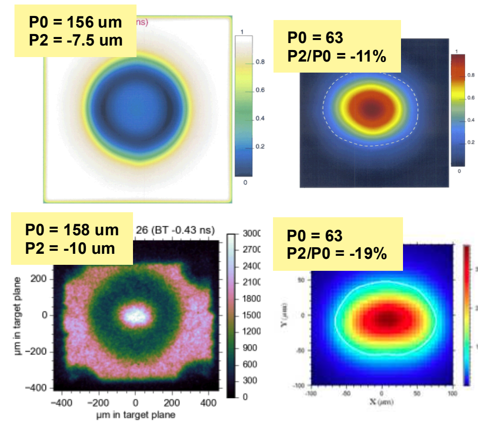

Fig 4: Simulated (top) and experiment (bottom) inflight and stagnation images for 0.6 mg/cc fill in 6.72–mm diam. hohlraum

Intermediate fill hohlraums

A 2-shock (6.5 ns) HDC experiment using an intermediate ρ_{fill} = 0.6 mg/cc and a larger 6.7 mm diameter hohlraum appears to have found a "sweet spot" where the HYDRA HFM using unclamped CBET (no ad hoc corrections) is able to predict the inflight and stagnated shape, as shown in Fig. 4. This experiment has little backscatter and modest CBET. However, subsequent experiments using a smaller 5.75 mm diameter hohlraum showed poor predictability for ρ_{fill} > 0.6 mg/cc, where inner cone SRS begins to appear.

New inline CBET/SRS calculation technique looks promising

To improve shape modeling and streamline the three-step process, "inline" models of CBET and SRS have been added to LASNEX and HYDRA. The inline CBET model uses the same coupled-mode equations as the offline script, but also includes inverse-bremsstrahlung absorption, refraction, spatially non-uniform laser spots, and ion-wave energy deposition. The inline treatment results in different transfer during the picket, when the lasers are heating the window material and absorption is important. Later in the pulse the differences are minor. In particular, ion heating by ion waves [3] raises T_{ion} by ~800 eV in the LEH, but does not significantly reduce CBET.

For the inline SRS model, the measured escaping SRS power and wavelength are input (not calculated), as before. Plane-wave coupled-mode equations are solved for the laser and SRS light, including SRS light absorption and Langmuir wave deposition, along the laser ray paths. The different refraction of SRS light is not accounted for. The SRS light effectively originates at a seed point, where the net gain (coupling minus absorption) becomes positive. The LASNEX inline CBET and SRS models were run for the high-foot CH symcap shot N121130, which had substantial CBET and inner cone SRS. A set of runs was done with constant CBET saturation clamp $\delta n_e/n_e = 10^{-3}$: a) three-step process, b) inline CBET but SRS removed at lens, and c) inline CBET and SRS. They all gave the same total x-ray drive, but all had very different shape. Case (c) had a much more pole-hot drive than the others (see Fig. 5), which is in the direction of experimental data. The inline SRS model deposits inner-beam energy to Langmuir waves, which occurs mostly just inside the LEH, and results in a hotter LEH than case (b). This limits CBET. A small fraction of SRS light was re-absorbed. The major goal of this effort is a predictive shape model for high fill densities, with a physical formula for the saturation clamp instead of one adjusted by hand.

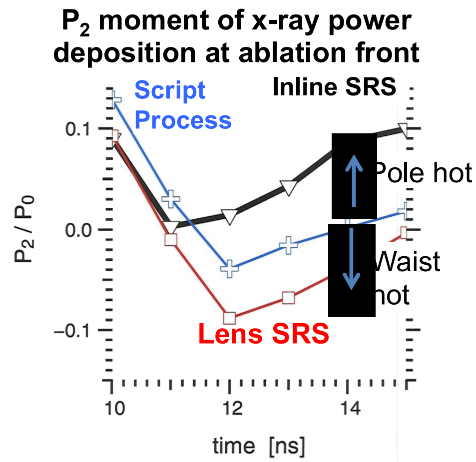

Fig 5: P2/P0 moment of radiation flux is more pole-high when SRS is calculated inline .

[1] P. Michel, et al., PRL 102, 025004 (2009)
[2] M.D. Rosen, et al., HEDP 7, 180 (2011)
[3] P. Michel, et al., PRL 109, 195004 (2012)